Hyperspectral Discrimination of Vegetation - What is Possible?

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ABSTRACT

This paper summarises recent research conducted within the Spatial Information Group at the University of Adelaide, which has aimed to apply hyperspectral imagery to tasks involving the discrimination of different plant types. The settings for the research have included both natural vegetation communities and horticultural enterprises in southern Australia. The paper discusses the relevance of the conventional spectral library concept for vegetation hyperspectral studies, comments on hyperspectral image analysis methodologies that appear to be useful for vegetation studies, and presents results to date.

Several studies have explored spectral differences between groups of plants using high resolution spectrometer reflectance measurements. These have included southern Australian arid zone plants, seagrasses and grape vine varieties. Statistical analysis has tested spectral separability of the groups relative to intra-group variation, and identified the spectral regions most significant in discrimination. Results have pointed to relatively broad spectral regions rather than narrow spectral features that were important in separating the groups, and showed that relative, not absolute differences existed between spectra for the plant types. The signatures and results from the studies should only be interpreted relative to their specific study areas. The spectral variability within plant groups that these studies have demonstrated has important implications for hyperspectral image-based discrimination and mapping of plants. The notion of a distinctive spectral signature for a plant species or group does not seem appropriate: plant types may be distinguishable with hyperspectral measurements, but only if their inherent variability is acknowledged and incorporated into the analysis. Similarly, the concept of a library of reference plant spectra for use in remote sensing studies needs to be tempered. Such a collection of plant spectra should contain far more than single examples for each species, and must take into account variations in leaves, plants, environments and climate across the geographic range of the species.

In the arid zone study (Lewis 2002a), visible-near infrared spectra of five groups of plants including Eucalypts, Acacias, ephemeral and perennial chenopod shrubs and other shrubs were classified using discriminant analysis, with the spectral regions most influential in the discrimination being the chlorophyll absorption near 680nm, the infrared beyond 720nm, followed by the blue-green and other visible wavelengths. Fair discrimination (Kappa = 0.48) was achieved with 70 wavebands spanning the visible - near infrared, but was slightly reduced with 16 selected narrow bands chosen to simulate CASI wavebands.

Examination of short-wave infrared reflectance spectra for some of these Australian arid zone species has increased understanding of their spectral characteristics over a range of conditions and informed hyperspectral image-based studies (Lewis *et al.* 2001). Short-wave spectra of several trees and shrubs often show detectable traces of cellulose and lignin absorption features, as well as specific narrow absorptions caused by plant oils and waxes, even though the plants are live, photosynthetic and often semi-succulent. These spectral expressions are possibly caused by the scleromorphic characteristics of these drought-adapted plants: strong development of foliar thickening tissue and cuticular waxes, as well as reduced leaf area as adaptations to prevent tissue damage and wilting under moisture stress.

The grape vine study, located in the Barossa Valley in South Australia, monitored visible-near infrared spectra of four varieties of vines on six dates throughout the 2000 growing season (Lacar *et al*. 2001a). The field reflectance spectra showed greatest difference at the red edge (~720nm), followed by the green reflectance peak and its wings in the visible. Cabernet Sauvignon and Semillon were the most significantly different pair of varieties throughout the visible region, while the differences at the red edge were mainly attributed to Semillon. In the derivative spectra regions of significant difference were narrower and potentially attributable to chlorophyll content, leaf structure or water content. Cabernet Sauvignon differed most from the other varieties at approximately 512nm and 580nm. The wavelengths that showed the greatest potential for discrimination between all four varieties were 512nm, 580nm, 611nm, 649nm, 690nm and 763nm.

In the seagrass study an extensive collection of visible-near infrared spectra of *Posidonia and Amphibolis* seagrass species and a variety of species of brown algae were tested for spectral variability and separability, and to determine the implications that this may have on approaches used for hyperspectral image analysis. Comparisons were made within species, between species, and in one case on different epiphyte loadings of a species to determine the variability in spectra. Preliminary analysis suggests that a group of brown algae, *Amphibolis antarcticus* and the two *Posidonia* species may be discriminated spectrally. It also seems that *P. angustifolia* and *P. sinuosa*, whilst being similar spectrally, are distinguishable from each other with a high level of accuracy (Sparrow and Lewis 2002).

Studies with hyperspectral imagery in a range of environments have shown promising levels of plant discrimination, although the analytical methods used have yet to fully incorporate the variation in plant spectra discussed above, many being based on image or spectral library reference signatures. Some studies have focused on particular species or vegetation components, while others have explored strategies for mapping vegetation communities. Several feature extraction methodologies have been explored in the course of these studies, building an understanding of the utility of particular approaches for different mapping tasks, vegetation types and environments. The studies have also placed emphasis, where possible, on collection of quantitative field data for validation of vegetation components that have been mapped from imagery. This is considered an important step for understanding and acceptance of image-derived maps by vegetation ecologists who have shown some reluctance to adopt digital image mapping technologies for their needs.

Automated spectral unmixing of Airborne Multispectral Scanner hyperspectral imagery successfully mapped several semi-arid vegetation components including tree species, undershrub types, plant litter and soil-encrusting lichens (Lewis *et al.* 2001). All spectral regions of the imagery, including the shortwave region from 1900-2500nm, yielded vegetation endmembers, several of which were significantly correlated with field measurements of plant cover. Several image endmembers departed from those typically used in conventional linear mixture analysis where contrasting "green" and "dry" plant spectra are used. Some trees appeared to be actively photosynthetic in the VNIR, while still displaying biochemical absorptions in the SWIR. Conversely, some understorey shrubs showed weak chlorophyll absorption in the VNIR, with SWIR reflectances more typical of "green" vegetation, dominated by water.

While this and many other studies have shown the potential of hyperspectral imagery for discriminating functional components and biochemical constituents, producing maps of the distribution and abundance of specific plant components or types, vegetation community inventory and survey requires mapping of vegetation and soil assemblages as integrated units. In this task, there has been little uptake of advanced image technology, although hyperspectral imaging has considerable potential to offer. Part of our research program has been directed towards developing methodologies that exploit the strengths of hyperspectral imagery for vegetation mapping and deliver products that are accepted by ecologists. HyMap airborne hyperspectral imagery was applied to problems of discriminating variation in vegetation composition and mapping vegetation communities in a southern Australian semi-arid mallee and chenopod shrubland environment (Lewis 2002b,c). Spectral absorption-depth methods were applied to chlorophyll, water, cellulose/lignin and oil/wax image spectral features to produce distribution and abundance maps of different vegetation components including trees, shrubs and dry plant litter. Surface soil and rock outcrops were mapped using clay, carbonate and iron oxide absorption features. Quantitative data on ground cover from field plots was significantly correlated with selected image endmembers, and served to verify the identity of the vegetation species mapped. Several image vegetation endmembers were combined to produce vegetation association maps that showed distributions similar to maps previously produced by conventional photo-interpretation and field sampling methods. The HyMap vegetation map however showed more detail about variation within communities and more precise definition of boundaries. Particular vegetation communities could be characterised by different endmember "profiles" or combinations and abundances of vegetation and soil end-members.

In shallow coastal waters HyMap imagery has been used to map the distribution of seagrass communities and sediment types (Dunk and Lewis 2000), and is being evaluated for mapping seagrass decline associated with coastal marine aquaculture. Distribution maps were produced of intertidal seagrass (*Zostera mucronata*), subtidal seagrass assemblages (*Posidonia australis* and *P. sinuosa*), a tidal inlet subject to pollutant discharge and suspended particulate matter. Several methods of feature extraction were evaluated, with spectral angle mapping assessed as being the mapping technique best suited to shallow water environments because of its simultaneous sensitivity to spectral shape and insensitivity to reflectance strength. Attenuation took effect and became apparent at approximately 580nm. Reflectance beyond 716nm could not be utilised as input for hyperspectral analysis due to either high light attenuation levels, or water surface roughness causing high levels of reflectance.

The experience gained from spectrometer studies of grape vine varieties was applied to mapping of two grapevine varieties were mapped using CASI imagery over a Barossa Valley vineyard in South Australia. Statistical analysis of image spectra from the two varieties showed significant differences in the visible region. Maximum likelihood classification was employed to map the two grape varieties present on the site, initially using 12 visible and near infrared CASI bands and repeated using a spectral subset of seven bands shown to be most significant in separating the varieties. Discrimination between Cabernet Sauvignon and Shiraz varieties was successful with 91.5% of vine rows correctly classified. Spectral subsetting did not improve classification and led to under classification of vine pixels.

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